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Methicillin-Resistant *Staphylococcus aureus* Infection or Colonization Present at Hospital Admission: Multivariable Risk Factor Screening To Increase Efficiency of Surveillance Culturing▽

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Identifying methicillin-resistant *Staphylococcus aureus* (MRSA) colonization or infection present at admission has become important in reducing subsequent nosocomial transmission, but the most efficient surveillance methods remain to be defined. We performed anterior nares surveillance cultures of all patients upon admission to and discharge from the general internal medicine floor in our community hospital over a 7-week period, and patients completed a questionnaire on MRSA risk factors. Of the 401 patients, 41 (10.2%) had MRSA upon admission. Of the 48 risk measures analyzed, 10 were significantly associated with admission MRSA, and 7 of these were independently associated in stepwise logistic regression analysis. Factor analysis identified eight latent variables that contained most of the predictive information in the 48 risk measures. Repeat logistic regression analysis including the latent variables revealed three independent risk measures for admission MRSA: a nursing home stay (relative risk [RR], 6.18; 95% confidence interval [95% CI], 3.56 to 10.72; $P < 0.0001$), prior MRSA infection (RR, 3.97; 95% CI, 1.94 to 8.12; $P = 0.0002$), and the third latent variable (factor 3; RR, 3.14; 95% CI, 1.56 to 6.31; $P = 0.0013$), representing the combined effects of homelessness, jail stay, promiscuity, intravenous drug use, and other drug use. Multivariable models had greater sensitivity at detecting admission MRSA than any single risk measure and allowed detection of 78% to 90% of admission MRSA from admission surveillance cultures on 46% to 58% of admissions. If confirmed in additional studies, multivariable questionnaire screening at admission might identify a subset of admissions for surveillance cultures that would more efficiently identify most admission MRSA.

Methicillin-resistant *Staphylococcus aureus* (MRSA) continues to be a cause of significant morbidity and mortality. Infection with MRSA, compared to methicillin-sensitive *Staphylococcus aureus* strains, has been associated with higher mortality rates (4, 9, 11, 14), longer hospital stays, and higher hospital charges (1, 9, 27, 30). In recent years, the prevalence of community-acquired MRSA has increased in certain segments of the community, resulting in admission to hospitals of increasing numbers of patients who are MRSA positive at admission and can then spread the organism in the hospital. These findings have increased the need to devise systems that efficiently screen admitted patients in order to identify those at high risk for having MRSA and isolate them to prevent subsequent nosocomial spread.

Presently a highly contested question is whether to culture all patients for MRSA at hospital admission, a proposition that has been criticized as too expensive (32, 38). To identify a more cost-effective middle ground, we undertook a quality improvement study in our hospital to identify high-risk groups who could be cultured selectively upon admission so as to detect all patients with MRSA upon admission more efficiently. Commonly, investigators have made a distinction between MRSA colonization and MRSA infection when assessing associated risk factors. Given that our objective was to identify all patients who were MRSA positive upon admission and potentially could spread MRSA to other patients in the hospital, we counted all patients with a positive screening or clinical culture within 48 h of hospital admission as having "admission MRSA" regardless of where the organism might have been acquired.

In the past, clinical investigators have used univariate and multivariable analyses to identify risk factors that are independently associated with MRSA. These statistical tools, while valuable, do little to explore the collinearities between potential risk factors. Simply stated, several risk factors that might not be independently associated with MRSA individually might be more importantly associated with MRSA as part of a group of related risk factors. To look more deeply into the collinearities among the risk factors associated with admission MRSA, we used factor analysis, a technique that is relatively new to the field of infectious diseases but has been used effectively in other scientific fields, such as psychiatry and genomics (24, 28, 33).

MATERIALS AND METHODS

Subjects and data collection. The study population included patients admitted directly, or transferred from other floors, to the general internal medicine floor between the dates of 22 April and 10 June 2005. We collected surveillance swabs

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from both anterior nares of all 401 patients upon admission to and discharge from the unit. We cultured only the anterior nares to detect MRSA colonization, since it has been demonstrated repeatedly that for adults, this is the most sensitive and cost-efficient screening site, and the addition of other sites has been shown not to add significantly to sensitivity (23, 35, 37). Although different types of MRSA are associated with nosocomial spread, the issue facing hospitals is identifying any MRSA upon admission, regardless of where it originated; therefore, we also included those patients admitted with clinical cultures positive for MRSA within the first 48 h of hospital admission regardless of the surveillance culture results. On the study's internal medicine floor, it is common practice to obtain cultures from potentially infected sites; therefore, no selection bias was introduced by including admission MRSA-positive clinical cultures. At the time of nasal swab collection, patients filled out a survey questionnaire, with a nurse available to clarify questions as needed. The questionnaire included questions regarding history of MRSA infection; prior hospitalization in the past year; prior antibiotic use and compliance in the past 6 months; nursing home stay in the past year; number of comorbidities (sum of the number checked from a list including diabetes mellitus, heart disease, cancer/malignancy, hypertension, respiratory disease, intestinal disease, and renal failure); dialysis in the past year; central venous catheter in the past year; surgery in the past year; tracheostomy in the past year; percutaneous feeding tube in the past year; skin breakdown in the past year; use of a fitness center, community pool, or tanning salon; contact sports; type and frequency of illicit drug use in the past year and ever; number of sex partners in the past year; males having sex with males (MSM); household size; family member with history of MRSA infection in the past year; bathing frequency; jail stay in the past year; and recent history of homelessness. The study was undertaken as a quality improvement and infection control measure within our hospital.

Case definition of admission MRSA. A case of admission MRSA was defined as a patient who had a nasal surveillance culture and/or a clinical culture positive for MRSA collected within 48 h of admission to the hospital.

Characterization of isolates. Samples were submitted to the laboratory in BD double-swab culturettes with Stuart's transport medium. The samples were plated directly onto BD CHROMagar selective for MRSA, which has a sensitivity of 95.4% after 24 h of incubation, increasing to 100% after 48 h of incubation, and a specificity of 100% after 24 h of incubation without enrichment (13). CHROMagar plates were incubated as long as 48 h at 35°C in an ambient air (non-CO_2-enriched) environment. Plates were evaluated for significant growth at 24 and 48 h. Isolates were identified as MRSA on the basis of colony morphology on CHROMagar and were submitted for susceptibility testing. Susceptibility studies were performed on the Dade Microscan instrument using commercially prepared MIC panels inoculated according to the manufacturer's protocols and read after overnight incubation. Antibiotic susceptibility results were interpreted according to Clinical and Laboratory Standards Institute (CLSI; formerly NCCLS) standards (10). Forty (97.6%) of the 41 MRSA isolates that were obtained within 48 h of admission were typed by pulsed-field gel electrophoresis (PFGE) at the Texas Department of State Health Services Laboratory. Overnight cultures grown at 35 to 37°C on brain heart infusion plates were used to make cell suspensions. Two hundred microliters of the cell suspensions was treated with 5 μl of lysostaphin at 1 mg/ml. Plugs were cast with 1.2% SeaKem gold agarose from Cambrex and treated with a lysis solution (Tris, NaCl, NaOH, EDTA, Brij 58, sodium deoxycholate, *N*-laurylsarcosine). After a wash with Tris-EDTA buffer, the plugs were digested at room temperature with 20 U of SmaI restriction endonuclease from New England Biolabs. A 1.2% agarose gel was cast. The pulsed-field gel parameters were as follows: initial switch time, 2.0 s; 6 V/cm; final switch time, 50.0 s; included angle, 120; run time, 20 h. The gels were stained with ethidium bromide from Sigma. The gel images were analyzed using Molecular Analyst software from Bio-Rad. Comparisons were made using the local MRSA database.

Statistical methods. We examined the univariate associations of the risk measures with admission MRSA using the Frequency procedure of SAS (version 9.1; SAS Institute, Cary, NC) and using Fisher's exact test and the Cochran-Armitage trend test to test significance. We used the Logistic procedure of SAS to perform stepwise logistic regression analysis of admission MRSA cases with all risk measures in the pool of predictors. Review of the χ^2-to-enter statistics at each step of the analysis identified many collinear measures competing to enter the model. To attempt to understand the information in multicollinearities, we performed a factor analysis of the 58 risk measures, using the principal-axis method of factor analysis (with the squared multiple correlations of each variable with all other variables as the prior communality estimates) and varimax (orthogonal) rotation in the Factor procedure of SAS. To determine the number of factors to extract, we inspected the scree plot for a breakpoint and examined the clinical plausibility of the combinations of risk measures loading on the factors in alternative models with different numbers of factors. The model with eight factors appeared the most clinically plausible. We then extracted the eight orthogonal factor scales, created additional dichotomized indicator variables for the eight scales by arbitrarily dividing each at the 50th percentile, and added the continuous and dichotomized factor measures to the pool of the original risk measures for analysis in further stepwise logistic regression modeling. Multicollinearity was assessed by examining the changes in χ^2-to-enter of all variables remaining in the pool of predictors at each step, and the validity of the logistic regression models was assessed by calculating the Hosmer-Lemeshow goodness-of-fit statistic and the area under the receiver operating characteristic (ROC) curve (18). Finally, we used the Generalized Linear Modeling (Genmod) procedure of SAS to derive unbiased estimates of the relative risk of prevalence (prevalence RR) and 95% confidence interval (95% CI) of each variable in the final logistic regression model, according to the method of Spiegelman and Hertzmark (39).

TABLE 1. Comparison of admission MRSA-positive[a] and -negative groups by demographic and clinical characteristics

Characteristic	MRSA$^+$	MRSA$^-$	*P*
Total no. of patients	41	360	
Mean age (yr [SD])	47.7 (15.0)	47.6 (16.3)	0.97
No. (%) male	26 (63)	185 (51)	0.19
Mean length of stay (days [SD])	6.1 (6.3)	4.7 (6.6)	0.28
Admission MRSA[b] definition components (no. [%])			
Surveillance culture positive; no clinical culture performed	17 (41.4)		
Surveillance culture positive; clinical culture positive	9 (22.0)		
Surveillance culture not performed; clinical culture positive[c]	3 (7.3)		
Surveillance culture negative; clinical culture positive	12 (29.3)		

[a] Infection or colonization.
[b] Culture performed within 2 days of hospital admission.
[c] These patients were transferred from other wards where admission cultures were not performed. All three were surveillance culture positive upon arrival at our ward, >48 h after hospital admission.

RESULTS

Description of case patients and antibiotic susceptibility patterns. A total of 420 consecutive admissions were screened, and 401 (95%) patients agreed to participate. Of the participants, 264 (66%) were admitted directly to the internal medicine floor; 137 (34%) were transferred to the internal medicine floor from other hospital services.

Of the 401 patients studied, 41 (10%) had admission MRSA-positive cultures. Of the 41 case patients, 26 (63%) were positive by nasal surveillance culture and 15 (37%) were identified only by clinical culture (Table 1); 22 of the 26 positive surveillance cultures and all 15 positive clinical cultures were obtained within 24 h of admission. Of those cases identified by surveillance culture, nine were later identified by clinical culture as well. Thirty-eight of the 41 MRSA isolates underwent antibiotic susceptibility testing; 2 (5%) were susceptible to erythromycin, 33 (87%) to clindamycin, 36 (95%) to gentamicin, 37 (97%) to trimethoprim-sulfamethoxazole, 36 (95%) to tetracycline, and 38 (100%) to vancomycin. A single susceptibility pattern (resistant to ampicillin, penicillin, oxacillin, cefazolin, ceftriaxone, and erythromycin and susceptible to clindamycin, gentamicin,

TABLE 2. Association of binomial risk measures with admission MRSA infection or colonization

Risk measure[a]	Not exposed		Exposed		RR[c]	95% CI	*P*
	n/*N*[b]	Rate (%)	*n*/*N*	Rate (%)			
History of nursing home stay[d]	33/386	8.5	8/15	53.30	6.24	3.51–11.09	<0.0001
Lives in a nursing home	33/386	8.5	8/15	53.30	6.24	3.51–11.09	<0.0001
History of wound or skin infection[d]	22/295	7.5	19/106	17.90	2.40	1.36–4.26	0.0044
Lives in a home or apartment	12/57	21.1	29/344	8.40	0.40	0.22–0.74	0.0077
History of MRSA infection ever	35/382	9.2	6/19	31.60	3.45	1.66–7.18	0.0078
Took antibiotics as an outpatient[e]	25/314	8	16/87	18.40	2.31	1.29–4.13	0.0083
Took antibiotics while in the hospital[e]	28/329	8.5	13/72	18.10	2.12	1.16–3.89	0.0290
History of IV drug use ever	35/375	9.3	6/26	23.10	2.47	1.15–5.34	0.0382
Uses IV drugs[d]	27/317	8.5	14/84	16.70	1.96	1.07–3.56	0.0409
Uses other illicit drugs[d]	18/237	7.6	23/164	14.00	1.85	1.03–3.31	0.0441
Man who has sex with men	37/386	9.6	4/15	26.70	2.78	1.14–6.80	0.0559
Lives alone	28/320	8.8	13/81	16.00	1.83	1.00–3.38	0.0642
Sexually promiscuous[d]	30/334	9	11/67	16.40	1.83	0.96–3.46	0.0773
History of jail stay[d]	32/349	9.2	9/52	17.30	1.89	0.96–3.72	0.0845
Antibiotics prescribed by physician[e]	25/291	8.6	16/110	14.50	1.69	0.94–3.05	0.0958
History of surgery[d]	28/313	8.9	13/88	14.80	1.65	0.89–3.05	0.1147
Homeless	35/369	9.5	6/32	18.80	1.98	0.90–4.34	0.1210
Ever in hospital isolation	30/332	9	11/69	15.90	1.76	0.93–3.35	0.1228
Admitted directly to study ward	10/140	7.1	31/261	11.90	1.66	0.84–3.29	0.1670
Male	15/190	7.9	26/211	12.30	1.56	0.85–2.86	0.1863
History of dialysis[d]	38/386	9.8	3/15	20.00	2.03	0.71–5.84	0.1899
Uses only clean needles for IV drugs	38/385	9.9	3/16	18.80	1.90	0.66–5.50	0.2178
Admitted from another hospital	31/266	11.7	10/135	7.40	0.64	0.32–1.26	0.2234
Sexually monogamous[d]	27/227	11.9	14/174	8.00	0.68	0.37–1.25	0.2456
History of hospitalization[d]	16/194	8.2	25/207	12.10	1.46	0.81–2.66	0.2489
Currently has a PEG tube	40/397	10.1	1/4	25.00	2.48	0.44–13.89	0.3515
Rarely takes a bath	41/387	10.6	0/14	0.00	NE[c]		0.3782
Shares needles for IV drugs	40/395	10.1	1/6	16.70	1.65	0.27–10.09	0.4787
Took all antibiotics prescribed[e]	25/267	9.4	16/134	11.90	1.28	0.71–2.31	0.4849
Overnight stay for surgery[d]	33/336	9.8	8/65	12.30	1.25	0.61–2.59	0.5079
Transferred from IMC unit	38/357	10.6	3/44	6.80	0.64	0.21–1.99	0.5998
Percutaneous catheter/medical device[d]	31/312	9.9	10/89	11.20	1.13	0.58–2.22	0.6948
Transferred from observation unit	39/369	10.6	2/32	6.30	0.59	0.15–2.34	0.7589
Sexually abstinent[d]	27/270	10	14/131	10.70	1.07	0.58–1.97	0.8612
History of PEG tube[d]	40/391	10.2	1/10	10.00	0.98	0.15–6.42	1.0000
Lives in jail	41/399	10.3	0/2	0.00	NE		1.0000
History of tracheostomy[d]	41/396	10.4	0/5	0.00	NE		1.0000
Currently has a tracheostomy	41/397	10.3	0/4	0.00	NE		1.0000
Took antibiotics at home[e]	39/381	10.2	2/20	10.00	0.98	0.25–3.76	1.0000
Goes to the gym	37/363	10.2	4/38	10.50	1.03	0.39–2.74	1.0000
Goes to the tanning salon	41/400	10.3	0/1	0.00	NE		1.0000
Plays contact sports	39/381	10.2	2/20	10.00	0.98	0.25–3.76	1.0000
Family contact with MRSA[d]	41/397	10.3	0/4	0.00	NE		1.0000
Family contact with skin infection[d]	39/376	10.4	2/25	8.00	0.77	0.20–3.01	1.0000
Shared towels with MRSA contact[d]	40/390	10.3	1/11	9.10	0.89	0.13–5.88	1.0000
Provided wound care to contact[d]	40/390	10.3	1/11	9.10	0.89	0.13–5.88	1.0000
Transferred from intensive care unit	40/383	10.4	1/18	5.60	0.53	0.08–3.65	1.0000
Transferred from telemetry unit	37/361	10.2	4/40	10.00	0.98	0.37–2.60	1.0000

[a] IV, intravenous; PEG, percutaneous endoscopic gastrostomy; IMC, intermediate care unit.
[b] *n*, number of patients with MRSA infection or colonization on admission; *N*, total number of patients exposed to the risk measure.
[c] NE, not estimable.
[d] In the past year.
[e] In the past 6 months.

trimethoprim-sulfamethoxazole, tetracycline, and vancomycin) was identified for 26 (67%) of the 39 isolates. For the 40 isolates tested by PFGE, 20 distinct patterns were identified. SM-Star-703 was identified for 15 (38%) of the 40 specimens tested, and the second most common pattern, SM-Star-538, was identified for only 4 specimens. SM-Star-703 is the pattern most commonly found among MRSA isolates tested at the Texas Department of Health Public Health Lab and is closely related to the USA 300 pattern (A. M. Valle-Rivera, personal communication), one of the primary types causing community-acquired infections nationwide (29). No PFGE pattern was significantly associated with any individual risk measures.

Univariate analysis. Of the 48 risk measures analyzed, 10 were associated significantly with admission MRSA colonization or infection, with risk ratios ranging from 0.40 to 6.24 (Table 2). Of the multinomial risk measures, we found significant dose-response relationships for days of prior hospitalization in the past year ($P = 0.016$), days previously on antibiotics in the past 6 months ($P = 0.005$), and years using intravenous

TABLE 3. Tests for dose-response effects of continuous risk measures for MRSA infection or colonization on admission

Risk measure[a]	n/N[b]	Rate (%)	RR	95% CI	P_{trend}[c]
Days of prior hospitalization in past yr					
0	16/194	8.2	1.00		
1–7	14/144	9.7	1.18	0.59–2.34	
>7	11/50	22.0	2.67	1.32–5.38	0.016
Days previously on antibiotics in past 6 mo					
0	18/238	7.6	1.00		
1–7	6/64	9.4	1.24	0.51–2.99	
>7	17/99	17.2	2.27	1.22–4.22	0.010
Yrs of IV[d] drug abuse, lifetime					
0	36/377	9.5	1.00		
1–4	2/8	25.0	2.62	0.76–9.05	
>4	3/11	27.3	2.86	1.04–7.87	0.023
Days in jail in past yr					
0	32/349	9.2	1.00		
1	2/15	13.3	1.45	0.38–5.51	
>1	6/34	17.6	1.92	0.87–4.27	0.10
Age group (yr)					
18–30	4/62	6.5	1.00		
31–45	18/121	14.9	2.31	0.82–6.52	
45–60	11/138	8.0	1.24	0.41–3.73	
61–75	6/52	11.5	1.79	0.53–6.00	
>75	2/27	7.4	1.15	0.22–5.90	0.79

[a] IV, intravenous.
[b] n, number of patients with MRSA infection or colonization on admission; N, total number of patients.
[c] P_{trend}, P value from Cochran-Armitage test for trend.

drugs ($P = 0.023$), with only a marginally significant dose response for days in jail ($P = 0.100$) and no dose response for age ($P = 0.79$) (Table 3).

Stepwise logistic regression analysis. In the stepwise logistic regression analysis, only 6 of the 10 dichotomous risk measures and only the age category 31 to 45 years from the continuous risk measures remained independently associated with admission MRSA (Table 4). The seven risk measures had adjusted risk ratios ranging from 1.82 to 10.81. This model fit the data well (area under the ROC curve, 0.80; Hosmer-Lemeshow goodness-of-fit P value, 0.90). If the 15 patients with MRSA clinical infection at admission were excluded, the adjusted RRs remained similar but nonintravenous drug abuse and the 31- to 45-year age group were no longer statistically significant due to reduced statistical power (data not shown).

TABLE 4. Adjusted prevalence RRs of seven risk measures from a multivariable linear model of MRSA infection or colonization on admission[a]

Risk measure[b]	RR	95% CI	P
Nursing home stay in past yr	10.81	5.90–19.80	<0.0001
History of MRSA infection ever	3.72	1.64–8.42	0.0017
Male who has sex with men	3.24	1.34–7.88	0.0093
IV drug abuse in past yr	2.61	1.10–6.15	0.029
Non-IV drug abuse in past yr	1.88	0.93–3.83	0.080
Outpatient antibiotics in past yr	1.84	1.07–3.13	0.026
Ages 31–45	1.82	1.03–3.23	0.040

[a] Generated by the SAS Genmod procedure with the log link function (39). The corresponding multivariable logistic regression model had an area under the ROC curve of 0.80 and a Hosmer-Lemeshow goodness-of-fit P value of 0.90.
[b] IV, intravenous. The 31- to 45-year age group was compared with all other age groups.

TABLE 5. Adjusted prevalence RRs of two risk measures and a factor analysis scale from a multivariable linear model of MRSA infection or colonization on admission[a]

Risk measure	RR	95% CI	P
History of nursing home stay in past yr	6.18	3.56–10.72	<0.0001
History of MRSA infection ever	3.97	1.94–8.12	0.0002
Factor 3 scale of homelessness, jail stay, promiscuity, and drug use[b]	3.14	1.56–6.31	0.0013

[a] Generated by the SAS Genmod procedure with the log link function (39). The corresponding multivariate logistic regression analysis had a ROC area of 0.73 and a Hosmer-Lemeshow goodness-of-fit P value of 0.68.
[b] Dichotomized at the 50th percentile.

Factor analysis with revised logistic regression analysis. Factor analysis identified the best model as an 8-factor model (see Appendix). Adding the resulting eight factor scales to the pool of predictors in the stepwise logistic regression analysis yielded a more parsimonious 3-variable model that fit the data approximately as well as the 7-variable logistic model (area under the ROC curve, 0.73; Hosmer-Lemeshow goodness-of-fit P value, 0.68 [Table 5]). The first two variables, prior nursing home stay in the past year (RR, 6.18) and history of MRSA (RR, 3.97), were the two strongest variables in the previous seven-variable model (Table 4). However, the third variable, factor 3 (dichotomized) (RR, 3.14), represented the combined effects of homelessness, a jail stay in the past year, promiscuity (two or more sex partners in the past year), and illicit drug use (intravenous and other) in the past year.

Accuracy and screening burden of risk measures. In assessing the usefulness of the various risk measures for increasing the efficiency of admission surveillance culturing for MRSA, we found that the individual risk measures significantly associated with admission MRSA, used alone, lacked sufficient sensitivity (i.e., they detected too small a percentage of admission MRSA cases) to be useful in screening (Table 6). Hospitalization in the past year had the highest sensitivity (61%) of the individual risk measures (the sensitivity was 69% if patients with clinical MRSA infections were excluded). All of the multivariable risk measures had substantially higher sensitivities (Table 6). If all patients answering "yes" to any of the variables in a multivariable model were selected for admission surveillance cultures, 46% to 58% of admissions would have to be cultured (Table 6, screening burden) and 78% to 90% of admission MRSA would be detected (Table 6, sensitivity). Screening patient admissions with any of the seven risk measures in the initial logistic regression model shown in Table 4 would provide the most sensitive detection (90% of admission MRSA) while requiring cultures for 58% of admissions. Screening for the variables in the model in Table 5, derived from factor analysis, would detect a slightly lower percentage of admission MRSA cases but would require culturing a smaller percentage of admissions (Table 6).

TABLE 6. Accuracies and screening burdens of selected screening criteria for determining which patients have an admission screening culture for MRSA

Risk criterion for admission screening[a]	Accuracy (%)[b]		Screening burden (%)[c]
	Sensitivity	Specificity	
Univariate screening criteria			
Male who has sex with men	10	97	4
History of MRSA infection ever	15	96	5
IV drug use in past yr	15	94	6
Nursing home stay in past yr	20	98	4
Non-IV drug use in past yr	34	81	21
Outpatient antibiotics in past yr	39	80	22
Age 31–45	44	71	30
Hospitalization in past yr	61	49	52
Multivariate screening criteria			
Homeless, jail, promiscuous, or drug abuser (factor 3)	78	52	51
Any of the 6 measures in Table 4 other than age 31–45	80	58	46
Any of the 3 measures in Table 5	83	50	53
Any of the 7 measures in Table 4	90	46	58

[a] IV, intravenous.
[b] Sensitivity, percentage of MRSA-positive admissions that would be assigned to having an admission surveillance culture. Specificity, percentage of MRSA-negative admissions that would be assigned to having no admission surveillance culture.
[c] Screening burden, percentage of all admissions that would be assigned to having an admission surveillance culture.

DISCUSSION

Our findings provide possible new insight into the profiles of patients who bring MRSA into a hospital, insight that might be exploited to improve the efficiency of surveillance for admission MRSA. Logistic regression analysis of a large battery of admission risk measures identified a model consisting of only seven risk measures that strongly predicts admission MRSA. Besides the expected high risk of admission MRSA for patients with a past history of MRSA infection and those who recently were in a nursing home, our factor analysis identified a latent factor, factor 3, defined by combinations of homelessness, promiscuity, intravenous drug use, other illicit drug use, and a recent stay in jail, that predicted admission MRSA approximately as well. When this latent variable was introduced into the multivariable logistic regression analysis, all five of its component risk measures became nonsignificant, indicating that this one latent variable captures all the predictive information for admission MRSA risk of all five component risk measures. Further research of this phenomenon might produce an efficient method for defining the subset of patients to screen for admission MRSA.

Factor analysis, sometimes called principal-component analysis, is a data reduction method increasingly used in biomedical science to interpret data sets with large numbers of independent variables showing complex patterns of multicollinearity (24, 28, 33). Epidemiologic studies most often deal with multicollinearity by performing multivariable analyses to identify the best set of risk measures that independently predict the outcome and reject the collinear measures that did not make it into the final model as "not independently associated." Such models give an overly simplistic picture by implying that the final model variables are singly important and the rejected collinear variables are not. A latent variable identified by factor analysis may give a truer picture by demonstrating that a component of risk is conferred by a combination of the collinear variables best measured by the latent factor scale rather than by the single most strongly associated variable alone. In our study, factor analysis identified a new complex risk factor that may be useful, along with the two simpler characteristics identified, for focusing admission cultures to detect admission MRSA more efficiently.

Our multivariable model of admission MRSA and the risk measures that contribute to the latent variable factor 3 appear plausible in light of prior research. History of nursing home stay in the past year and history of MRSA infection are well-known and expected sources of admission MRSA (12, 17, 21, 22). Intravenous drug use, high-risk sex, and homelessness have each been found to be independent risk factors for MRSA infection or colonization in some settings (3, 6–8, 15, 25, 40); however, while many studies have described MRSA infection and colonization within jail populations (2, 6, 7, 34), this study is the first to show that a history of jail stay, a component of factor 3, may be associated with admission MRSA.

Two of the other risk measures—MSM and an age of >75—were the only displaced measures to maintain residual explanatory power, but when they were entered into the model with factor 3, they were not quite significant and thus did not appear in the final model. We examined the strength of association of MSM with each of the eight latent factors from the factor analysis and found it not to be highly associated with any of them. While some of its association with admission MRSA could be attributed to the latent variable factor 3, MSM appeared to explain a small component of admission MRSA risk independent of any of the other factors, suggesting some other risk attribute of MSM that this study, due to its relatively small size and perhaps unmeasured characteristics, was unable to explain. Future studies should test whether infection with human immunodeficiency virus, not measured in our study, might explain this residual association.

Our study found the prevalence of MRSA colonization in our patient population to be 8.7%, which is higher than the findings of similar studies (20–23, 26). Including those patients with clinical MRSA infections and negative surveillance cultures, the prevalence of admission MRSA actually was 10.2% in this study population. Without active surveillance methods, 17 (41%) of the 41 patients with admission MRSA would not have been identified. Although these 17 patients were found only to be colonized with MRSA, it has been shown that patients with only MRSA colonization can be significant sources for the spread of MRSA in a hospital (5, 12, 17, 19, 31, 36). If rapid MRSA identification methods, such as CHROMagar or PCR, were used for admission surveillance cultures but not for clinical cultures, active admission surveillance would provide advance identification of MRSA for 26 (63%) of the 41 patients with admission MRSA.

One advantage of our study was the availability of a relatively large hospital population with a higher prevalence of admission MRSA than that found in many similar studies; this gave it more statistical power for analysis of risk factors. Also, use of the recently described generalized linear modeling approach for multivariable estimation of RRs when outcomes are not rare (36) provided unbiased prevalence RR estimates for the risk measures appearing in our logistic regression models.

TABLE A1. Factor loadings of 50 risk measures on eight orthogonal factors explaining MRSA infection or colonization on admission

Risk measure[a]	Factor loading[b]							
	F1	F2	F3	F4	F5	F6	F7	F8
History of taking antibiotics	87[c]	−4	−3	3	7	6	5	0
Took all antibiotics prescribed	83[c]	−4	−10	−1	10	1	7	−4
Took antibiotics as an outpatient	73[c]	−7	0	5	−2	−5	5	12
Antibiotics prescribed by physician	72[c]	4	−5	−7	6	5	2	−4
Took antibiotics while in hospital	66[c]	−4	4	15	−2	−6	5	14
Doctors used gown in room	33[c]	1	9	−1	−5	−3	7	16
History of MRSA infection	30[c]	7	4	−1	−1	−3	4	4
Took old, leftover antibiotics	27[c]	8	−1	−3	−2	9	11	−13
History of wound or skin infection	24[c]	−6	13	17	−7	4	21	3
Transferred from another hospital	1	96[c]	−3	6	15	−14	2	1
Transferred from telemetry unit	2	48[c]	−18	−7	11	11	−20	22[c]
Transferred from IMC unit	0	41[c]	14	2	29[c]	−19	0	−4
Transferred from observation unit	−4	38[c]	−5	9	−8	−22[c]	28[c]	−11
Transferred from intensive care unit	3	36[c]	3	9	−15	10	−2	−10
First hospital admission	−1	−94[c]	2	−4	−14	14	−2	−1
Homeless	2	−13	66[c]	9	−2	1	−15	10
Lives alone	−2	−1	55[c]	32[c]	9	−16	−16	12
History of jail stay	4	−1	43[c]	−13	−1	9	3	8
Uses illicit drugs (nonintravenous)	1	1	42[c]	−20	3	21[c]	16	−3
Sexually promiscuous	1	−3	34[c]	−8	15	50[c]	14	−16
Uses intravenous drugs	6	4	30[c]	−5	29[c]	29[c]	41[c]	−14
Uses only clean needles	1	−2	16	−4	33[c]	22[c]	39[c]	−15
Lives in jail	0	5	20	−5	7	3	5	1
Male gender	1	2	19	8	5	−5	−12	−7
Man who has sex with men	0	−2	13	−2	0	−2	4	−7
Lives in home or apartment	3	7	−66[c]	−37[c]	7	−1	17	−5
History of NH or LTC facility stay	8	−3	4	62[c]	−8	8	−9	7
Lives in NH	7	1	5	60[c]	−9	5	−8	3
Sexually abstinent	4	−3	−2	51[c]	21[c]	−40[c]	2	−2
Ages 76–90	−7	9	−6	48[c]	−12	−7	−3	−7
Currently with PEG tube	0	9	−15	40[c]	9	9	1	4
Ages 61–75	11	4	−22[c]	28[c]	−7	−17	−1	8
Lives with one other person	7	−5	−12	−25[c]	−5	−25[c]	−8	−17
Ages 31–45	6	11	26[c]	−30[c]	−25[c]	30[c]	1	15
Has only one sex partner	2	2	−29[c]	−51[c]	−28[c]	−1	−10	11
History of tracheostomy	3	1	1	−2	78[c]	−5	−16	13
Currently with tracheostomy	−2	5	4	−4	76[c]	−3	−15	15
History of PEG tube	8	6	−17	30[c]	35[c]	9	4	7
Shares needles	−2	8	15	−4	32[c]	7	7	5
Ages 16–30	−9	−13	−21[c]	5	9	66[c]	1	−10
Goes to community gym or pool	−2	−1	2	−2	4	30[c]	−2	−8
Plays contact sports	0	−13	9	2	−1	24[c]	−8	0
Ages 46–60	−4	−9	7	−20	29[c]	−64[c]	0	−10
Contact with skin infection history	14	−3	−4	−3	−6	−4	68[c]	6
Helped with wound care	7	−5	−3	−2	−3	−2	62[c]	8
Shared towels with contact	6	−4	−1	−1	−7	−4	53[c]	−1
Contact with history of MRSA	11	9	−1	−2	0	−3	31[c]	5
History of surgery	8	0	6	−2	−6	−7	11	76[c]
Overnight stay for surgery	0	−4	4	−4	0	−8	6	74[c]
History of hospital stay	40[c]	−9	−2	9	10	2	2	43[c]
Indwelling catheter	15	−3	−8	4	19	−4	8	40[c]
History of hemodialysis	11	6	−3	0	18	−4	−4	30[c]

[a] IMC, intermediate care; NH, nursing home; LTC, long-term care; PEG, percutaneous endoscopic gastrostomy.

[b] F, Factor. Factor loadings from principal-factor analysis were multiplied by 100 and rounded to the nearest integer. The variables "goes to a tanning salon" and "rarely takes a bath" did not load strongly on any of the eight factors.

[c] Value above the root mean square of all values in the table (>20).

While our study population was larger than those in many similar studies, a larger study population will be needed to characterize some of the more subtle associations uncovered, such as some potentially independent risk associated with MSM. In addition, allowing nurses to help patients with the questionnaire could have interjected misclassification, but since neither the nurses nor the patients knew at the time who was MRSA positive, the misclassification is most likely nondifferential and therefore not an information bias. The restriction of the study patients to mostly adult internal medicine and postsurgical patients, with no pediatric or obstetrical patients, limits somewhat the insight into other potential MRSA risk determinants unique to other patient groups in the hospital.

The recent debate over whether hospitals should identify MRSA colonization at the time of admission has tended to focus on the two extreme options, culturing all admissions for MRSA or doing no admission surveillance culturing (32, 38). Patients admitted with either MRSA infection or colonization can transmit MRSA to other hospitalized patients. We found that admission surveillance culturing could identify between 41% and 63% of admission MRSA that either would not be detected or would be detected days later by clinical cultures. Comprehensive admission culturing, however, is expensive. This study provides new insight into the risk factors associated with admission MRSA and suggests an efficient middle ground in the debate: a recommendation to screen admitted patients initially with a short questionnaire or interview consisting of questions that would identify most admission MRSA and to perform admission surveillance cultures only on patients with a positive response to any of the questions.

In a similar study, measuring MRSA colonization at admission with slightly different data collection methods, Furuno et al. (16) determined that screening patients based on a single risk measure, hospitalization in the past year, detected 76% of admission MRSA while requiring surveillance cultures (surveillance culturing burden) for 65% of admissions; in our study, this measure included 61% of admission MRSA with a surveillance culturing burden of 52%. Screening for the presence of any of the five risk measures in our factor 3 detected 78% of admission MRSA with surveillance culturing burden of 51% of admissions. Adding a recent nursing home stay and a history of MRSA infection to these five risk measures further increased the sensitivity to 83% and the surveillance culturing burden to 53%. Screening instead for any of the seven variables in our first logistic regression analysis reached the top sensitivity of 90% but increased the culturing burden to 58% of admissions. The limited size of our study and its focus on a general internal medicine floor in a single hospital prevent us from concluding which model will prove the most useful and efficient in reducing the cost of surveillance culturing for admission MRSA in other hospitals. The main importance of our study lies in illustrating the potential usefulness of multivariable models in admission screening and potential approaches to developing such models. Further research should determine whether multivariable screening improves sensitivity and efficiency in other hospital settings and what risk measures contribute most powerfully to admission screening.

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APPENDIX

The factor analysis model used in this study involves eight orthogonal factors (Table A1).

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